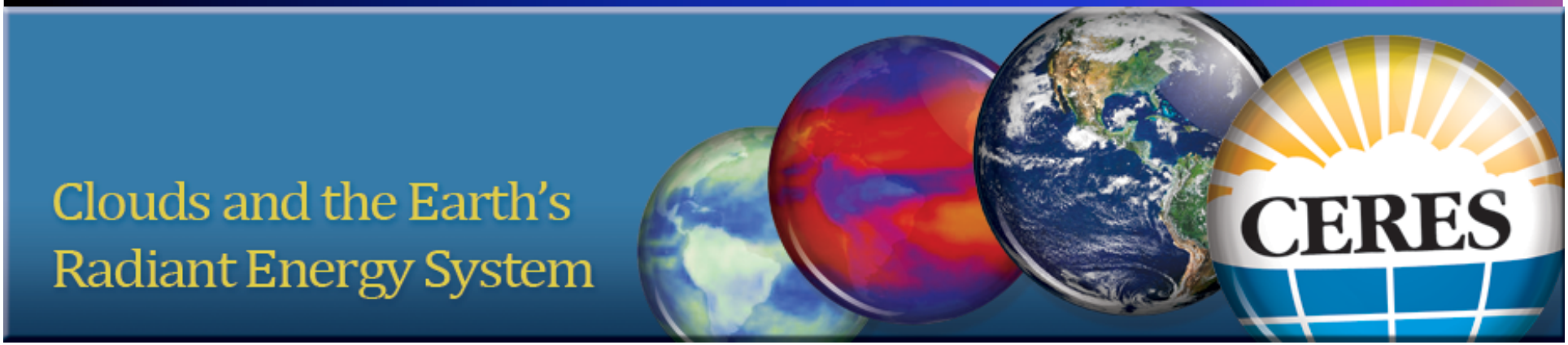
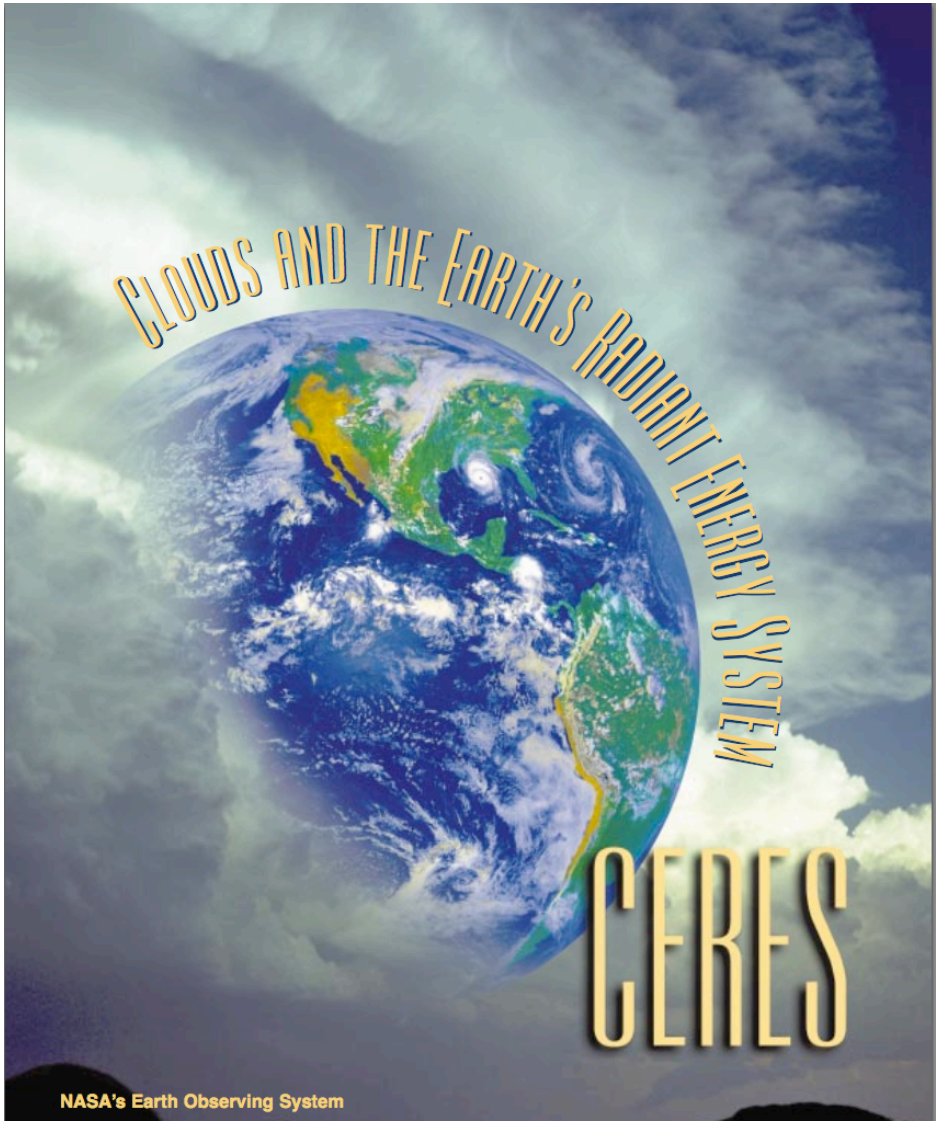


CERES FM6
Calibration Subsystem Performance Issues

Kory Priestley - Project Scientist
Audra Bullock - Chief Engineer

CERES Science Team Meeting
Scripps
October 29, 2013

Discussion Topics



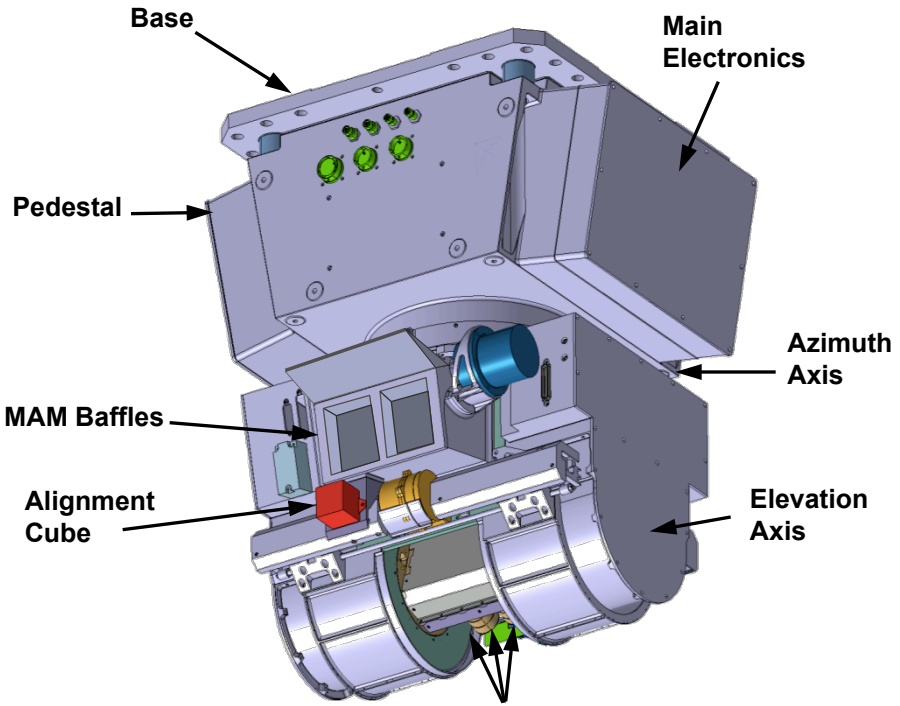
- **CERES Instrument**
  - Description
- **Radiation Budget Instrument Procurement Status**
- **Issues uncovered during FM6 ground calibration (May 2012)**
  - Solar Diffuser non-uniformity
  - SWICS Lamp instability
  - SWICS Reference Detector instability
- **Recovery Status**
- **Programmatics**
  - Schedule/Workplan

CERES Instrument

Clouds and the Earth's Radiant Energy System

- **Designed, manufactured and tested by TRW, Redondo Beach, CA (currently Northrop Grumman Aerospace Systems)**
- **Contains three sensor assemblies with cassegrain optics and thermistor bolometer detectors**
- **Sensors measure thermal radiation in the near-visible through far-infrared spectral region**
- **Sensor channels are coaligned and mounted on a spindle that rotates about the elevation axis**
- **Hemispherical sampling obtained with an azimuthal axis drive system**

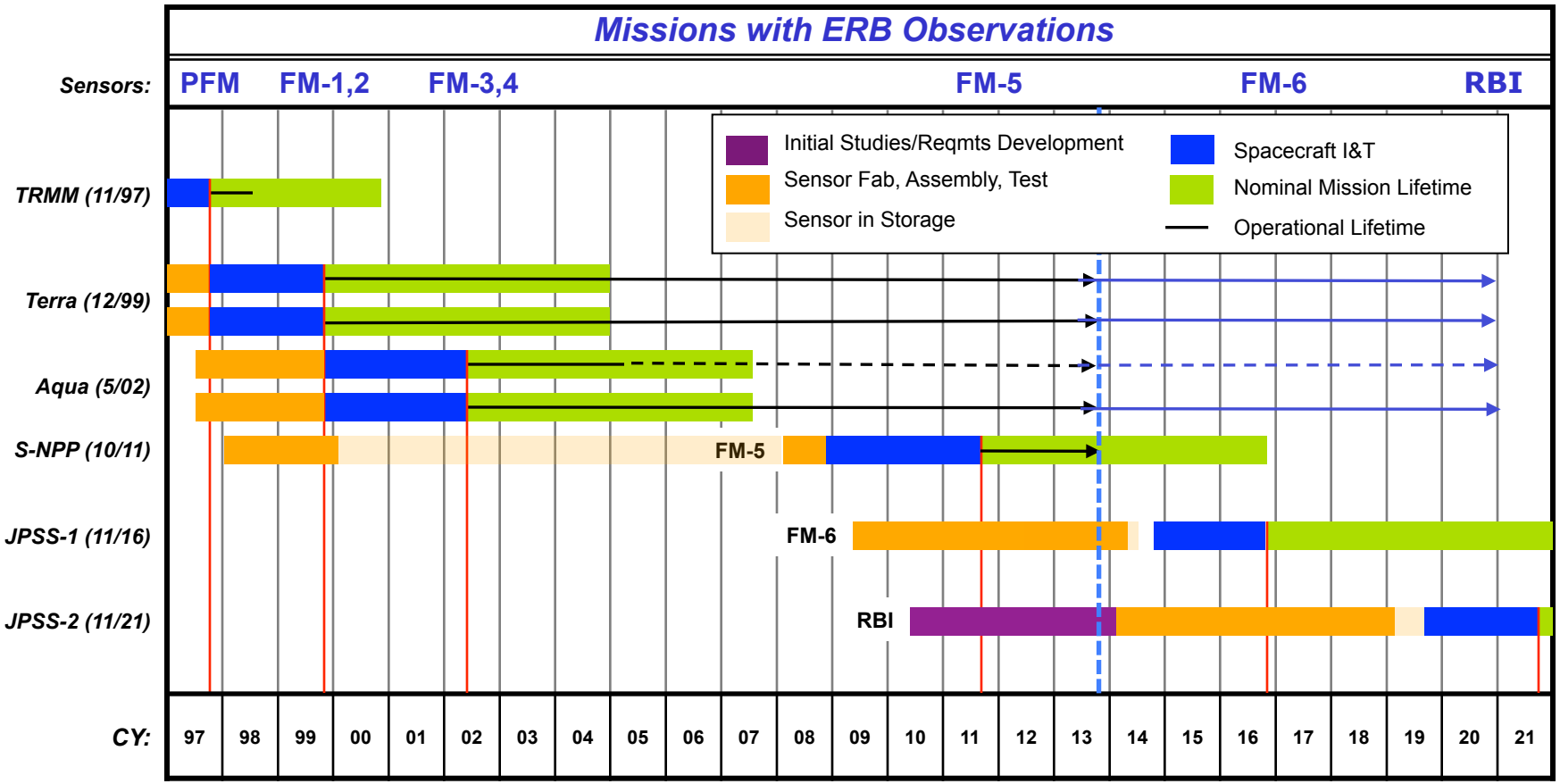
Orbits	705 km altitude, 10:30 a.m. descending node (Terra) or 1:30 p.m. ascending node (PM-1), sun-synchronous, near-polar; 350 km altitude, 35º inclination (TRMM)
Spectral Channels	Solar Reflected Radiation (Shortwave): 0.3 - 5.0 μm Window: 8 - 12 μm , 5 – 40 μm (FM6) Total: 0.3 to > 100 μm
Swath Dimensions	Limb to limb
Angular Sampling	Cross-track scan and 360º azimuth biaxial scan
Spatial Resolution	20 km at nadir (10 km for TRMM, 28 km for NPP)
Mass	45 kg
Duty Cycle	100%
Power	45 W
Data Rate	10 kbps
Size	60 x 60 x 70 cm (deployed)
Design Life	6 years



Climate Data Record Continuity

Clouds and the Earth's Radiant Energy System

CERES Flight Schedule



We now have over 51 years of flight experience with the CERES instruments

Radiation Budget Instrument : Status

RBI is intended to be a continuity measurement for the CERES observations

Request For Proposal (RFP) may be found at : https://www.fbo.gov , keyword is RBI.

- Final RFP released in June 2012
- Proposals received September 2013
- Evaluation of proposals underway
- Contract award anticipated Spring 2014

Radiometric Accuracy	CERES (k = 1)	RBI (k = 1)
Total Channel	Larger of 0.575 W/m^2-sr or 0.5%	Larger of 0.575 W/m^2-sr or 0.5%
Shortwave Channel	Larger of 0.75 W/m^2-sr or 1.0-%	Larger of .75 W/m^2-sr or 1.0%
Longwave Channel	Larger of 0.75 W/m^2-sr or 0.5%	Larger of 0.75 W/m^2-sr or 0.5%

CERES FM6 Instrument Performance Issues

- The CERES FM6 Team continues to pursue resolution of three issues:

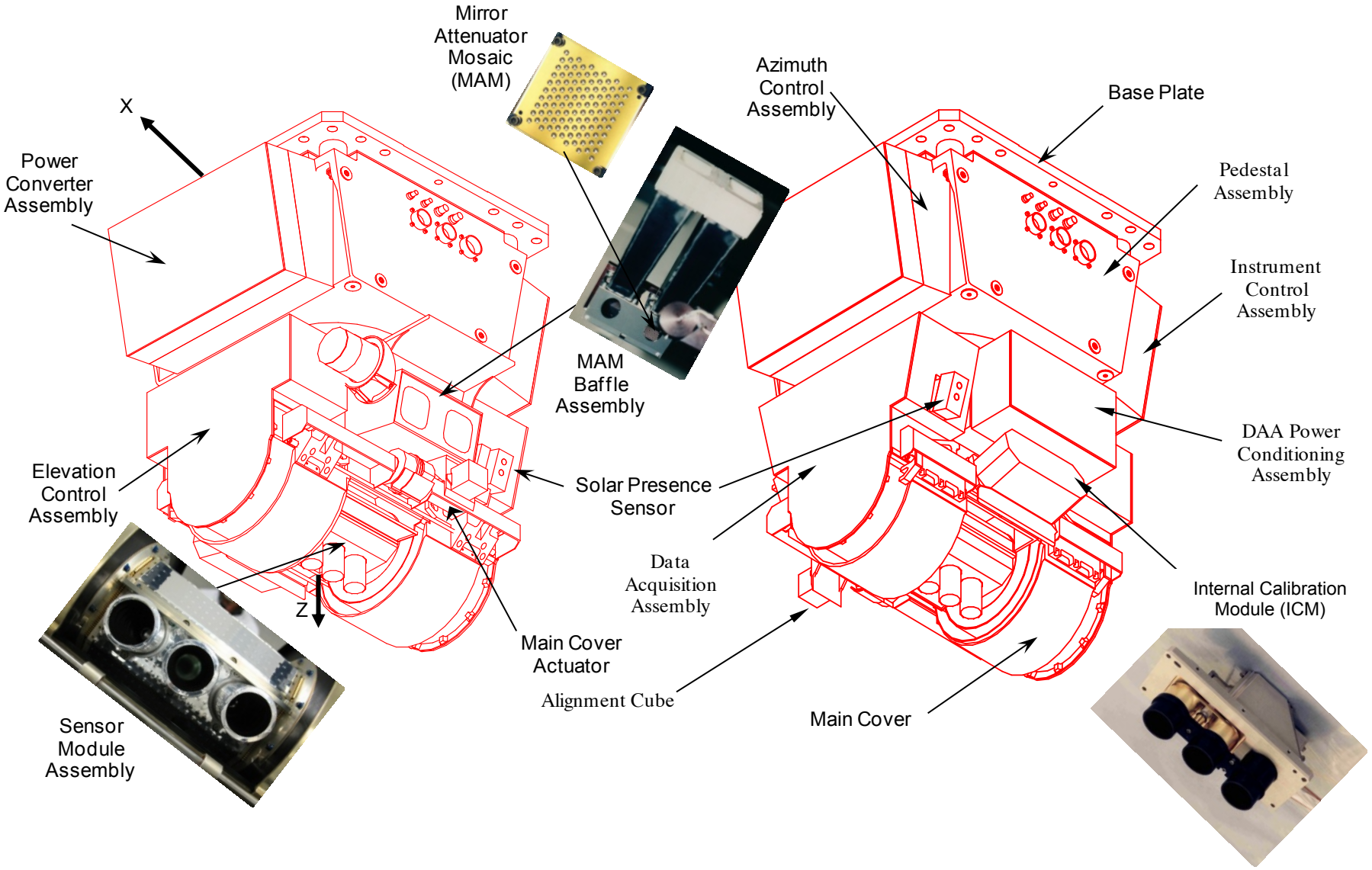
1. Solar Diffuser Mirror Attenuator Mosaic (MAM) scatter non-uniformity
2. Internal Calibration Module (ICM) lamp brightening
3. Internal Calibration Module (ICM) reference detector photodiode (PD) response decrease

- In May of 2012, FM6 had completed its baseline calibration with the following open issues:
  - SWICS lamp appears to have increased in brightness throughout the calibration campaign whereas the source monitor photodiode indicated a decrease in source output throughout the calibration campaign
  - Data from MAM scatter testing indicate spatial non-uniformity of >4.5% vs. 1.5% measured at component level.
  - If not resolved, CERES FM-6 will not meet its on-orbit SW channel performance accuracy requirements

Root cause has been identified for all items, workarounds complete, instrument completing Assembly and integration

CERES Instrument Description

Clouds and the Earth's Radiant Energy System



Performance Resolution Approach

ICM Resolution (Complete)

- Isolate Performance Problems
  - ICM Vacuum Test determined the Lamp and PD performance issues are confined to the ICM
  - ICM Diagnostic Test to further isolate performance issues
- Select replacement flight Lamp and PD from CERES parts

MAM Resolution (Complete)

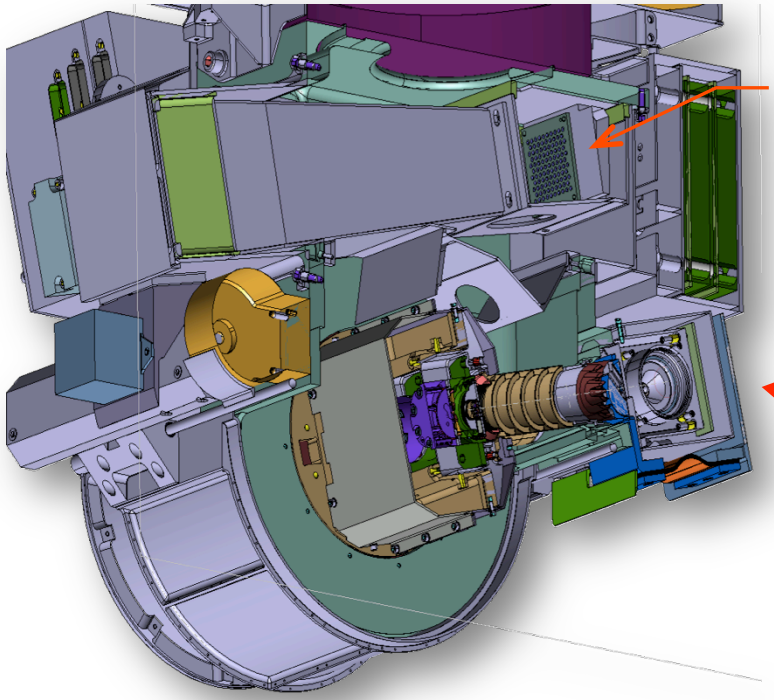
- Isolate Performance Problem
  - Diamond-Turned Tooling marks have been identified as the source of MAM performance issue
- Select replacement flight MAM from CERES heritage MAMs
  - Pre-condition MAM using AO asher from GRC

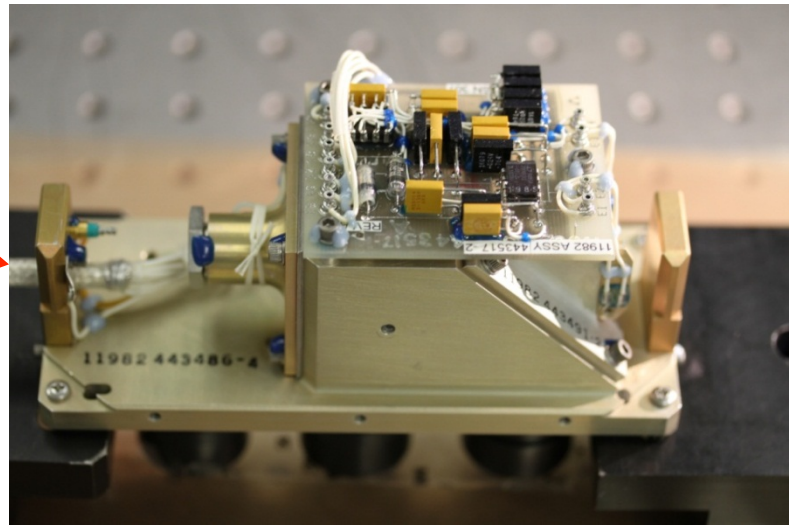
- Verify ICM performance in vacuum (Complete)
- Verify Instrument Performance (January 2013)
- Conduct SAR/PSRR (April 2013)

CERES FM6 Instrument Status

Clouds and the Earth's Radiant Energy System

- **CERES FM6 Calibration subsystem issues:**
  1. ***Solar Diffuser Mirror Attenuator Mosaic (MAM) scatter non-uniformity***
  2. Internal Calibration Module (ICM) lamp brightening
  3. Internal Calibration Module (ICM) photodiode reference detector response decrease





2 MAMs installed in CERES Instrument: SW & Total

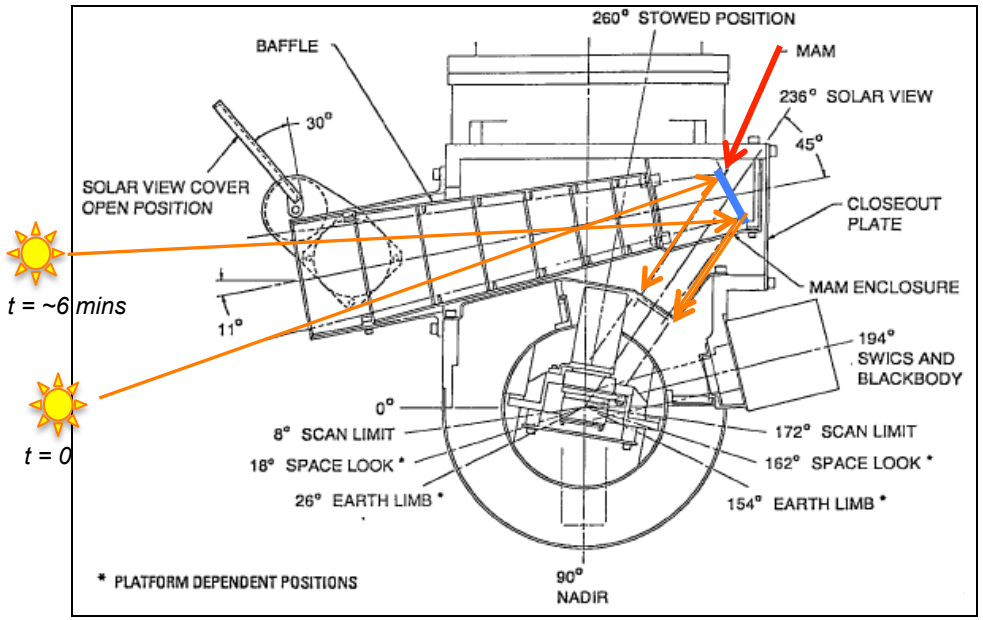
CERES FM6 MAM Overview

Clouds and the Earth's Radiant Energy System

- Mirror Attenuator Mosaics (MAMs) ***diffuse*** and ***attenuate*** incident solar energy so that the CERES Shortwave and Total Channels are presented with repeatable, on-scale radiance scenes over the range of incident angles experienced during periodic, on-orbit, solar calibrations.
- MAMs fabricated for FM6 are different than prior flight units
  - Substrate is Diamond Turned Aluminum vs. Electroformed Nickel
  - Coatings updated for improved resistance to Atomic Oxygen

MAM Goal
minimize variability in reflected solar energy over all incident angles

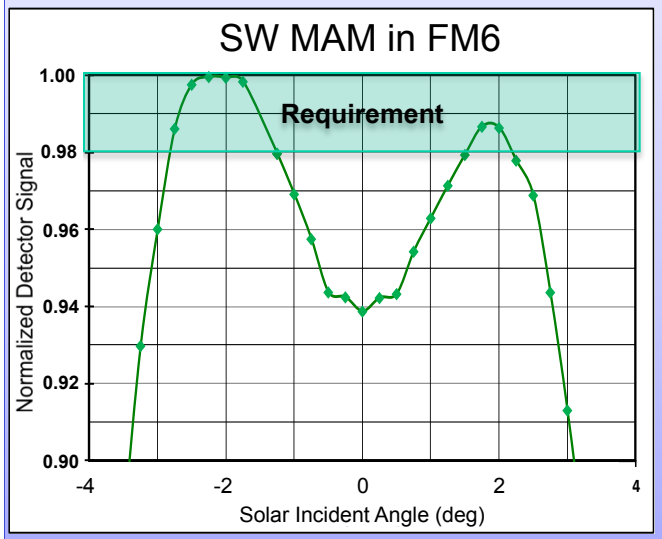
- Why did we change Fab process?
  - Diamond turned aluminum substantially easier to fabricate than electroformed nickel and electroform/grinding process has low yield ~25%.

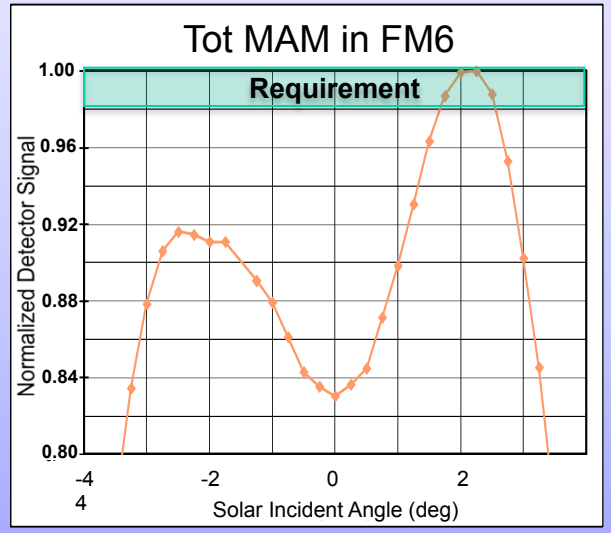


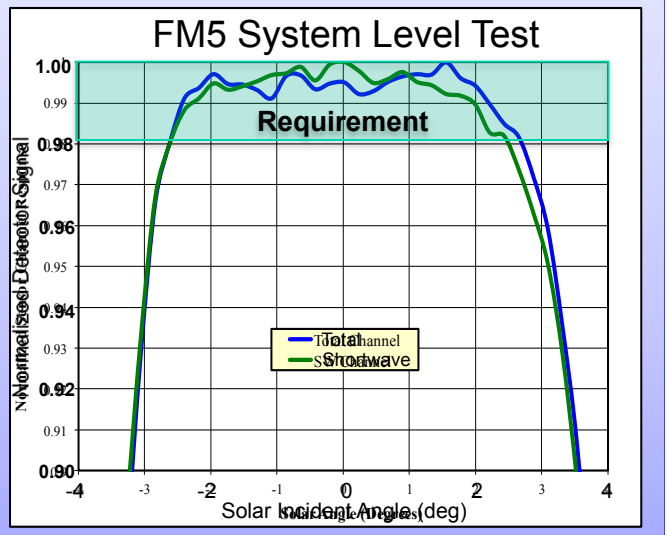
CERES MAM Assembly

MAM Scatter Uniformity Issue
(Instrument Level Testing)

Uniformity Requirement ±1% over 4.5° Solar Angle

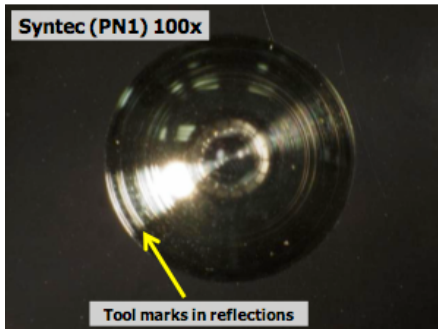


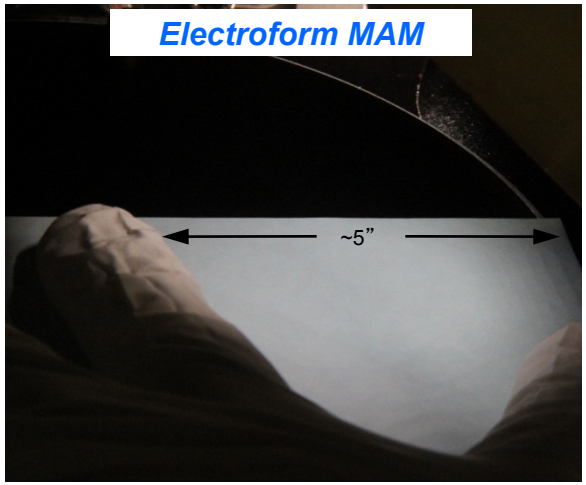




Two contributors identified:

- **Solar Simulator non-uniformity**
- **Diamond-turning resulted in fringed scatter pattern**

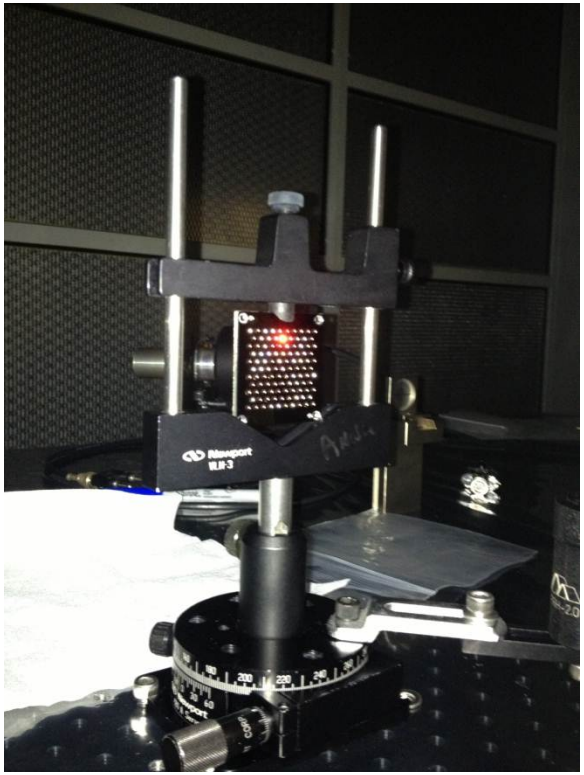




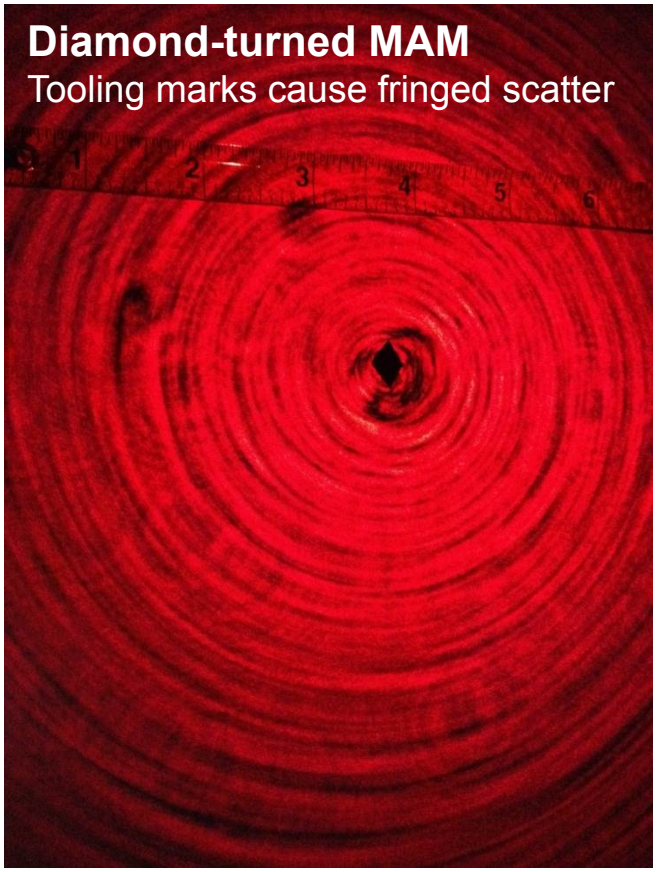
Diamond-turned vs Nickel MAM Laser Illuminating Single Dimple

Lesson Learned:

The diamond-turning process is plagued with issues of tooling marks



Diamond-turned MAM
Tooling marks cause fringed scatter

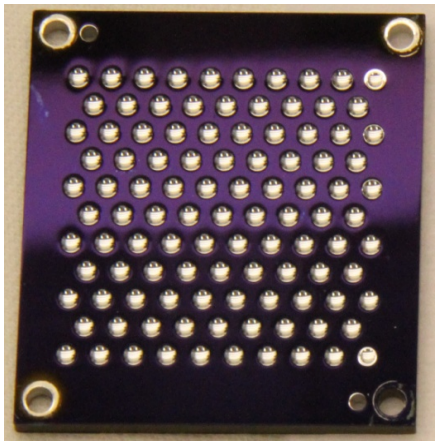


Electroformed MAM
Scatter is much more uniform

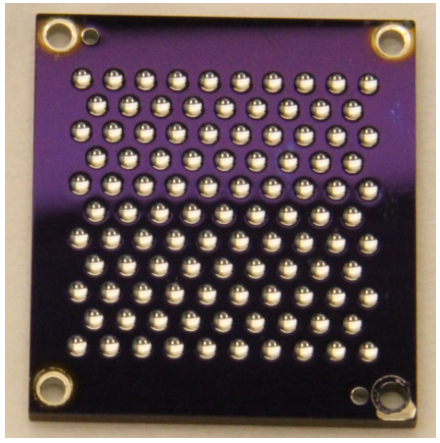
MAM Resolution

- **NG located 2 legacy MAMs of the FM4 vintage**
  - Parts removed from flight status in late 90's for surface blemishes
  - Parts bagged and stored in controlled environment during interim
- **Scatter uniformity meets requirements with margin**
- **AO coating susceptibility corrected**
  - LaRC & NG collaborated with GRC to fully oxidize protective coating *(Complete)*
- **MAMs upscreened and ready for installation 3 weeks ahead of schedule**
  - Coating adhesion testing *(Complete)*
  - Component scatter test post AO exposure *(Complete)*

S/N E1/B3

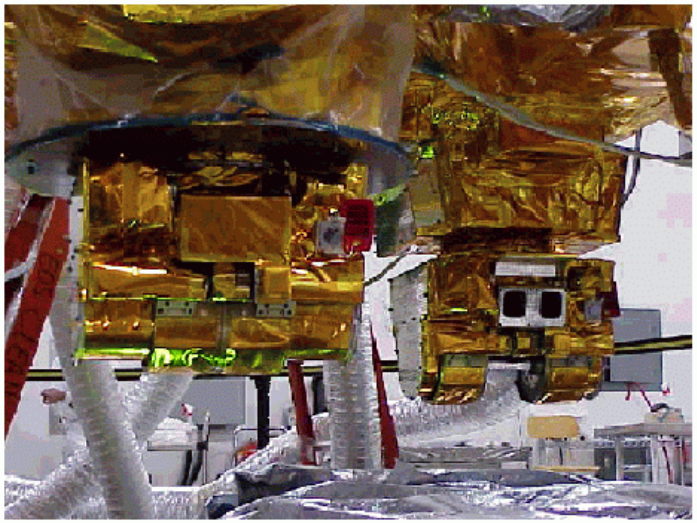


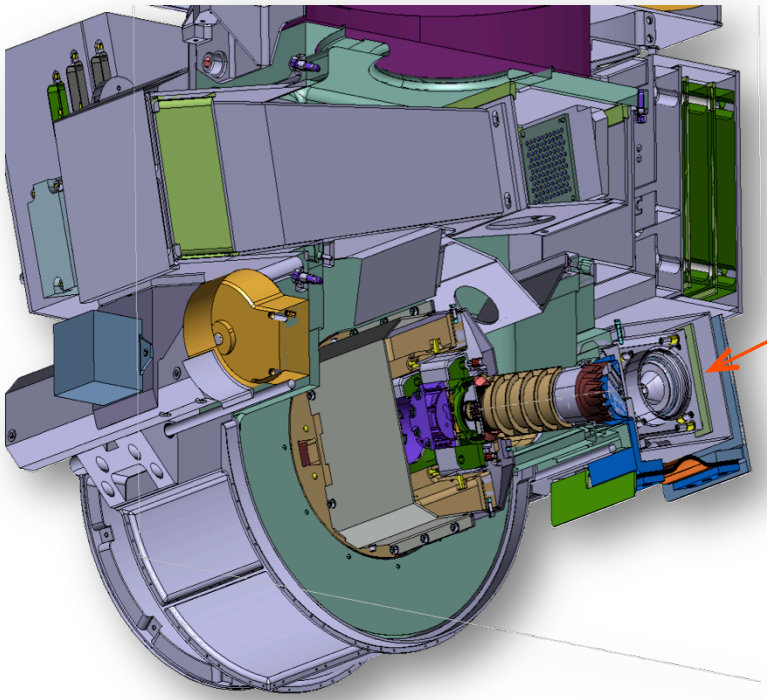
S/N C4

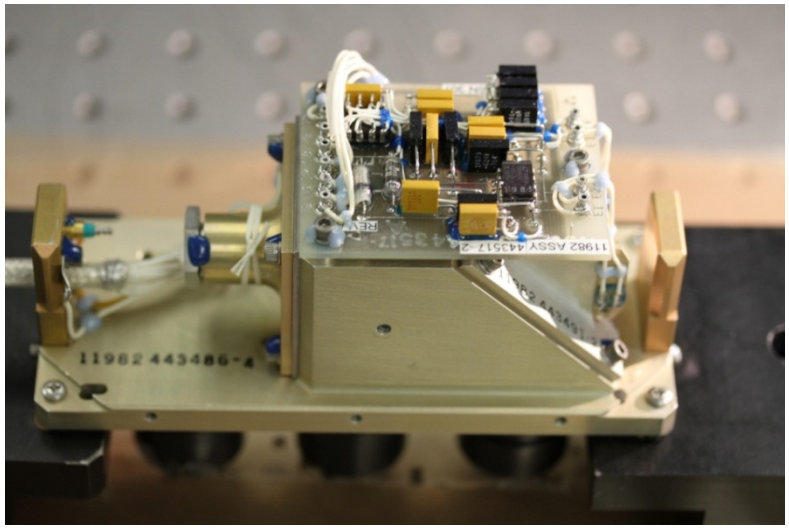


CERES FM6 Instrument Status

- **CERES FM6 Calibration subsystem issues:**
  1. Solar Diffuser Mirror Attenuator Mosaic (MAM) scatter non-uniformity
  2. ***Internal Calibration Module (ICM) lamp brightening***
  3. ***Internal Calibration Module (ICM) photodiode reference detector response decrease***







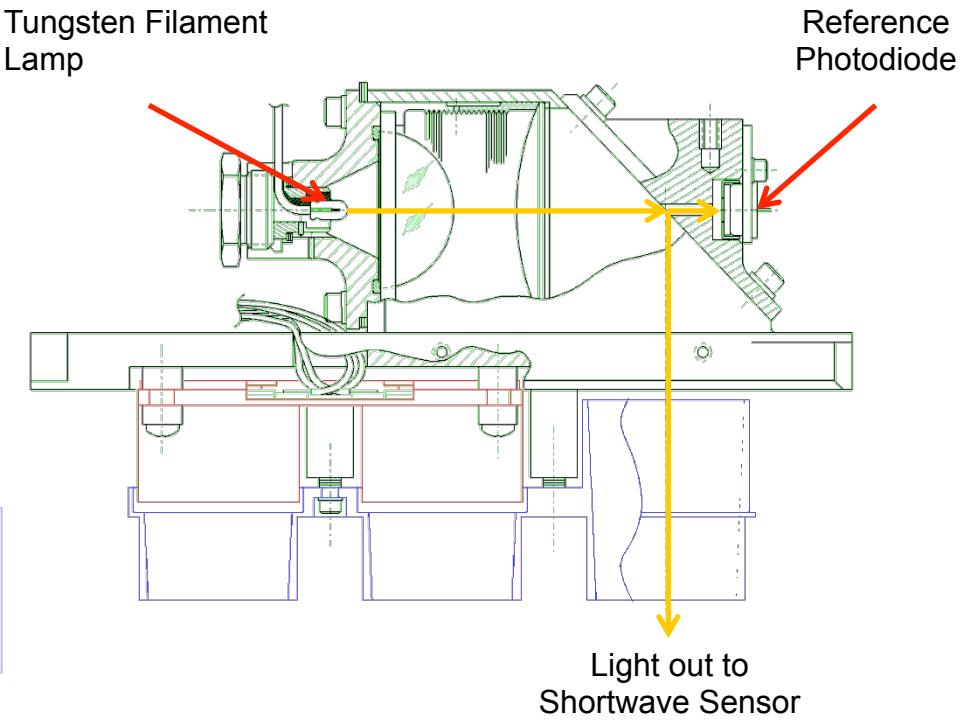
CERES Internal Calibration Module

ICM contains 2 subassemblies

Shortwave Internal Calibration Source (SWICS):
- Lamp and focusing optics
- Reference Detector
- Folding Mirror

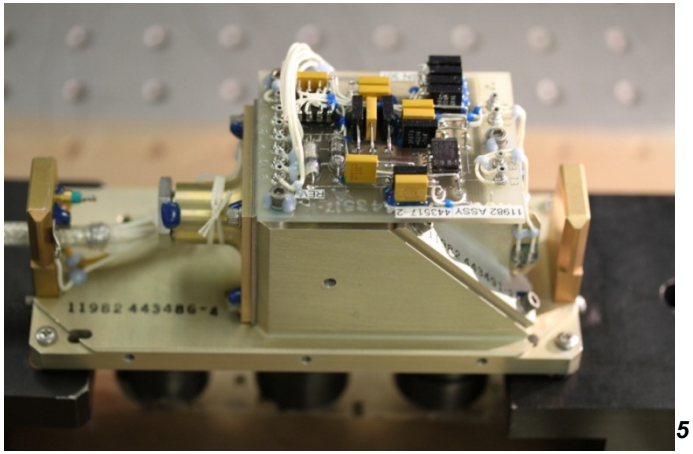
Internal BlackBody (IBB):
- Concentric grooved blackbodies
- Heaters and PRTs

During Calibration we view the SWICS lamp with two independent detectors CERES SW sensor and Reference Photodiode

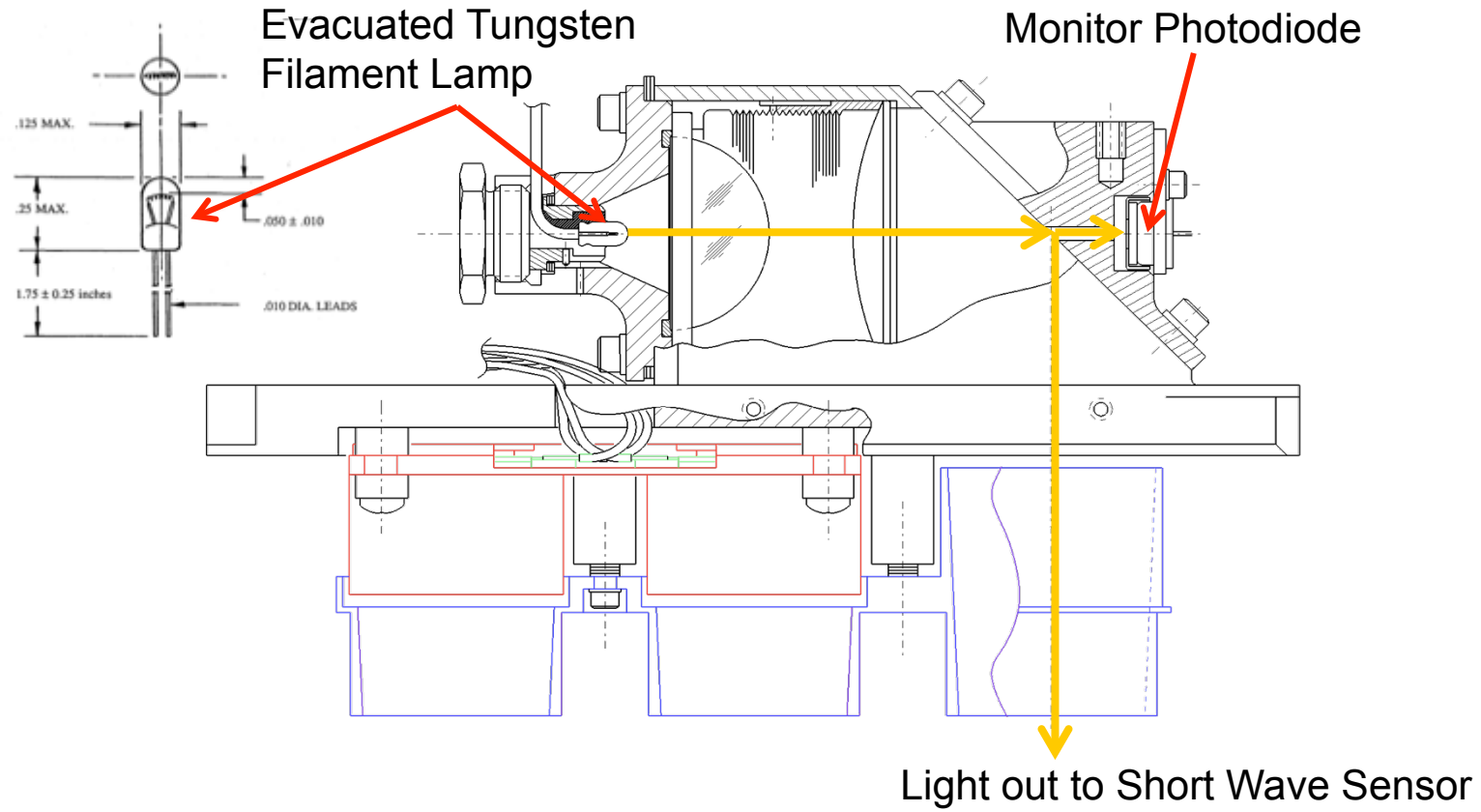


Instrument vacuum calibration results:

- **Shortwave sensor stability verified independently**
- **Shortwave sensor indicated SWICS brightening**
- **Reference photodiode indicated SWICS dimming**



CERES ICM SWICS Layout & Function

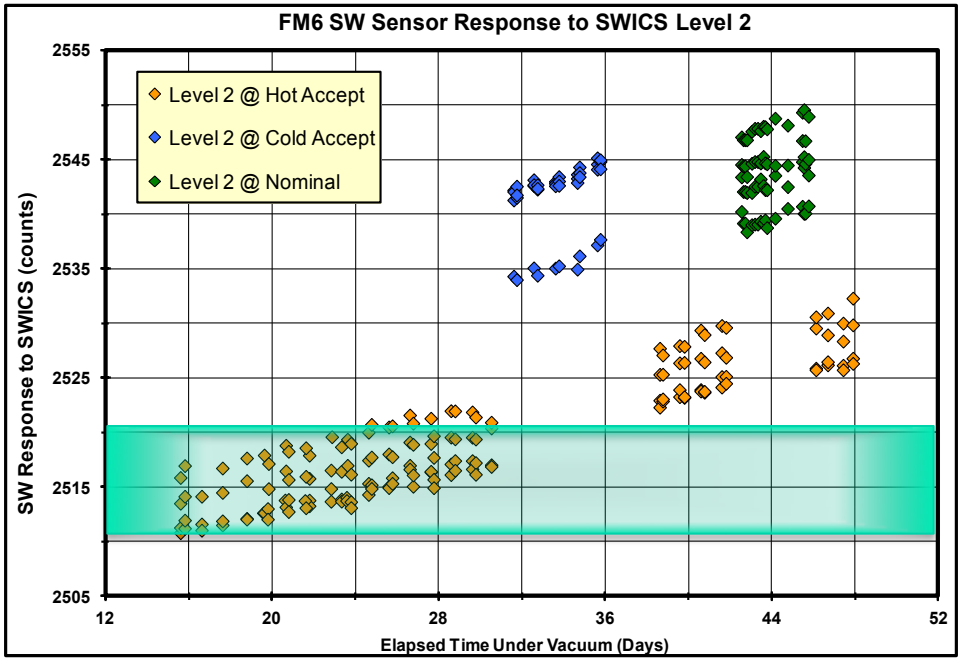


- **SW channel views lamp via protected aluminum-coated fold mirror**
- **PD views tungsten filament lamp via hole in fold mirror through band pass filter (700nm-800nm) mounted in front of the PD can (Note: PD spatially and spectrally subsamples the SWICS calibration lamp)**
- **Lens & diffuser (grit-blasted on flat side) distribute light across mirror**

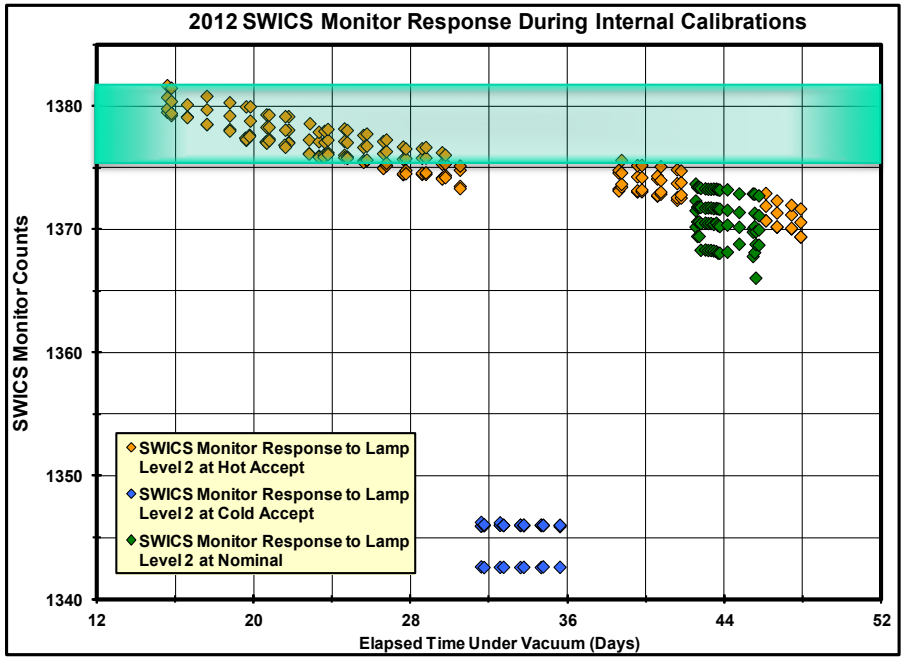
Instability of SWICS Lamp and Photodiode
(Instrument Level Testing)

The trends in the data below should be consistent or preferably flat.

Light Source : SWICS Lamp
Detector : CERES SW Channel
Conclusion : SWICS Lamp appears to be getting brighter



Light Source : SWICS Lamp
Detector : SWICS Photodiode Reference Detector
Conclusion : Photodiode Response Decreasing



- **ICM removed from instrument and tested under vacuum (Oct 2012, Jan 2013)**
- **Module-level test results *consistent* with instrument-level calibration (FM6 Instrument exonerated)**
- **Shifts with temperature are artifact of sensor and BB heater drive ground bias effect**
- **PD Data uncorrected for apparent source drift**
- **PD Response Drift Rate is a function of Instrument Temperature**

SWICS Instability

The trends in the SW channel and monitor PD measurements should be consistent or preferably flat.

SW channel can be independently verified during calibration

PD can only be illuminated by the SWICS lamp within the ICM

Thermally Corrected FM6 Instrument-Level Calibration Data

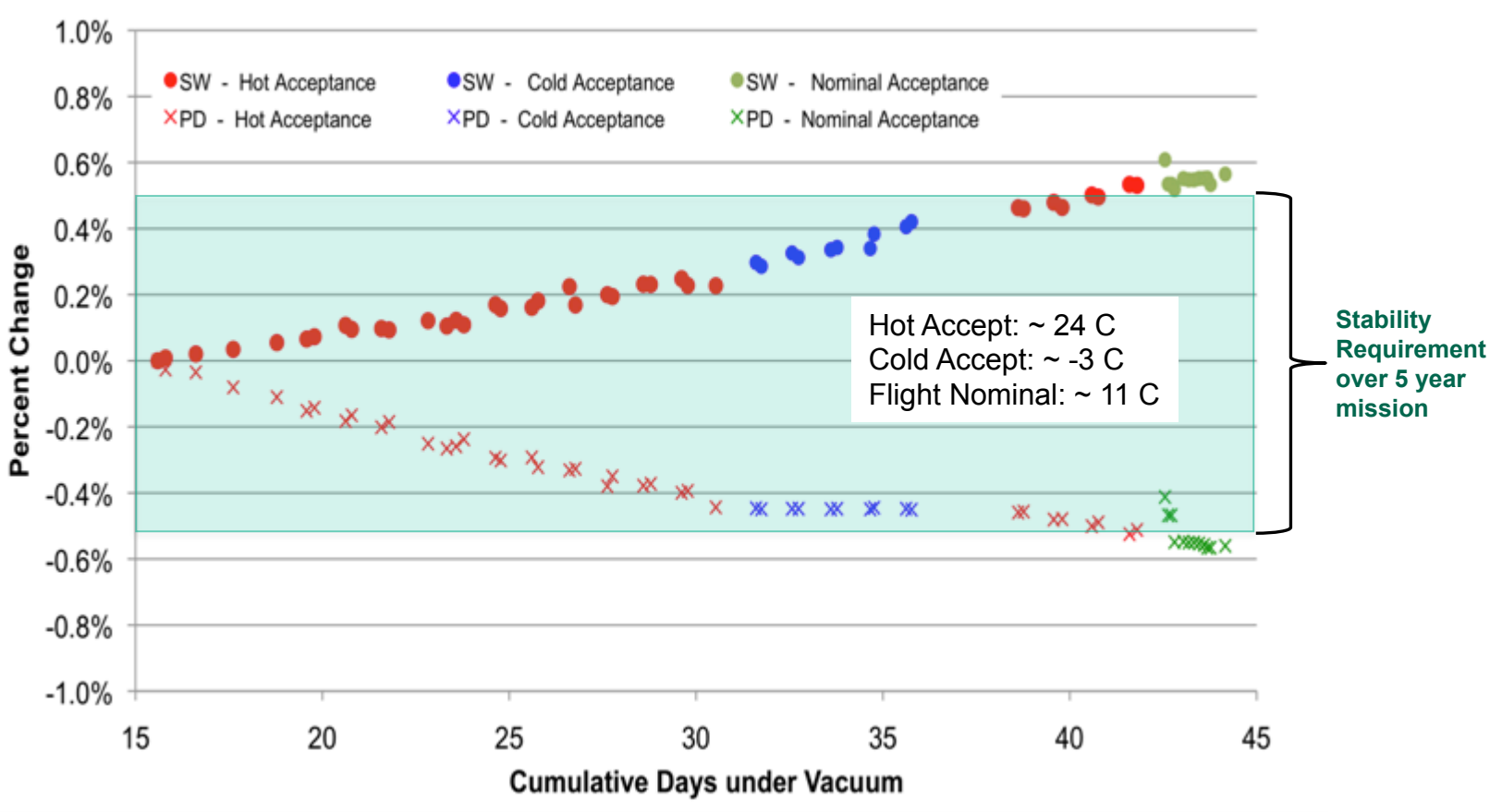
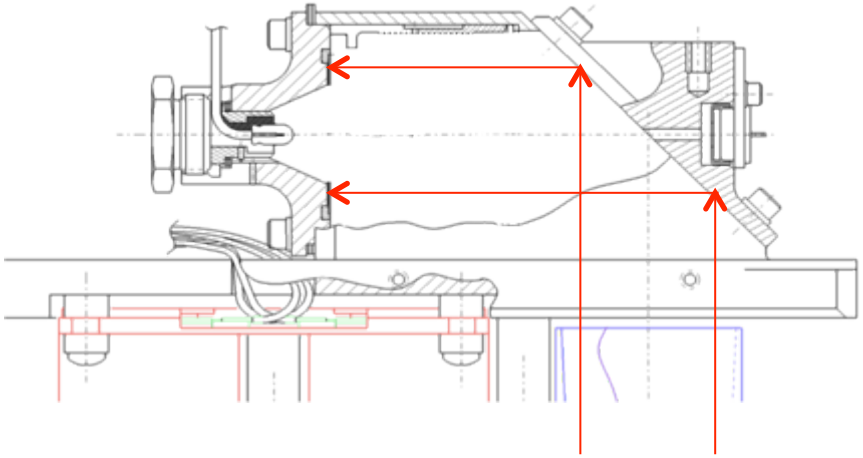
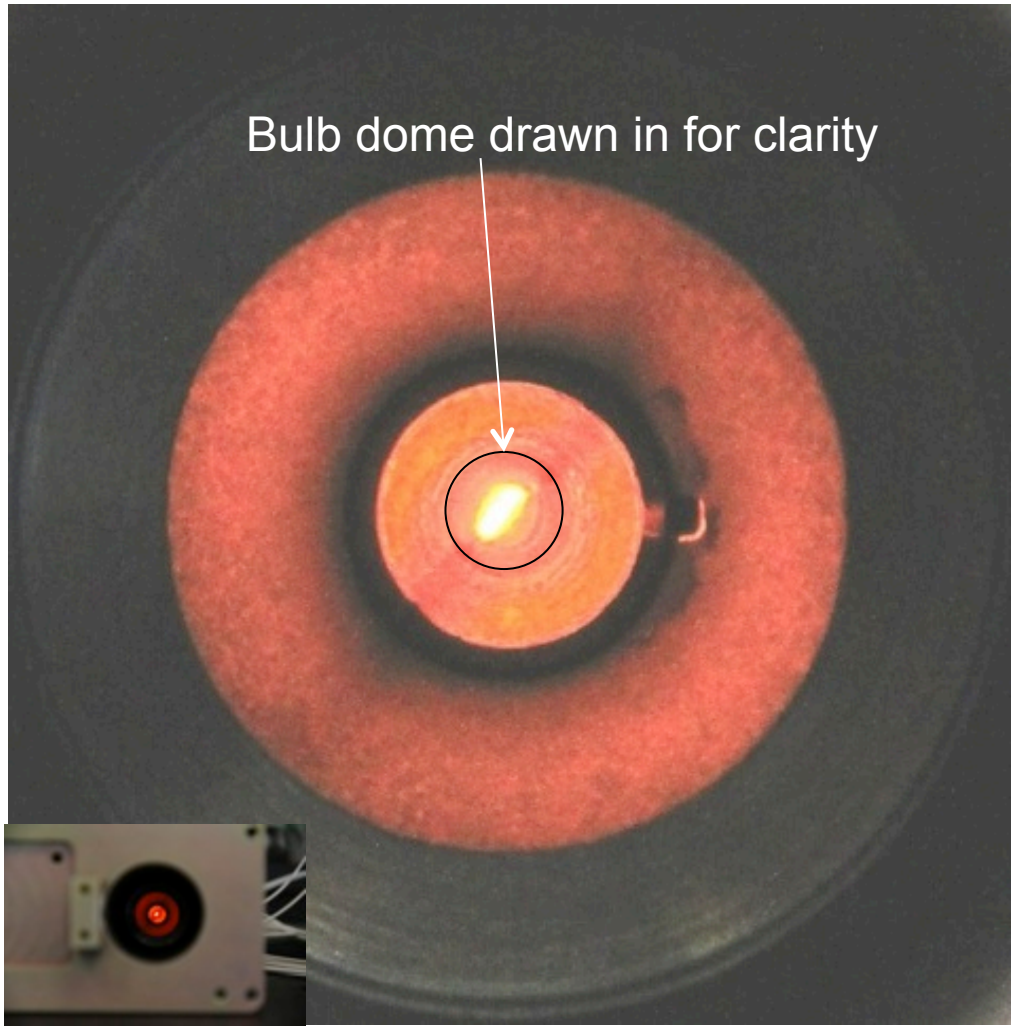


Image of Lamp Assembly in the ICM

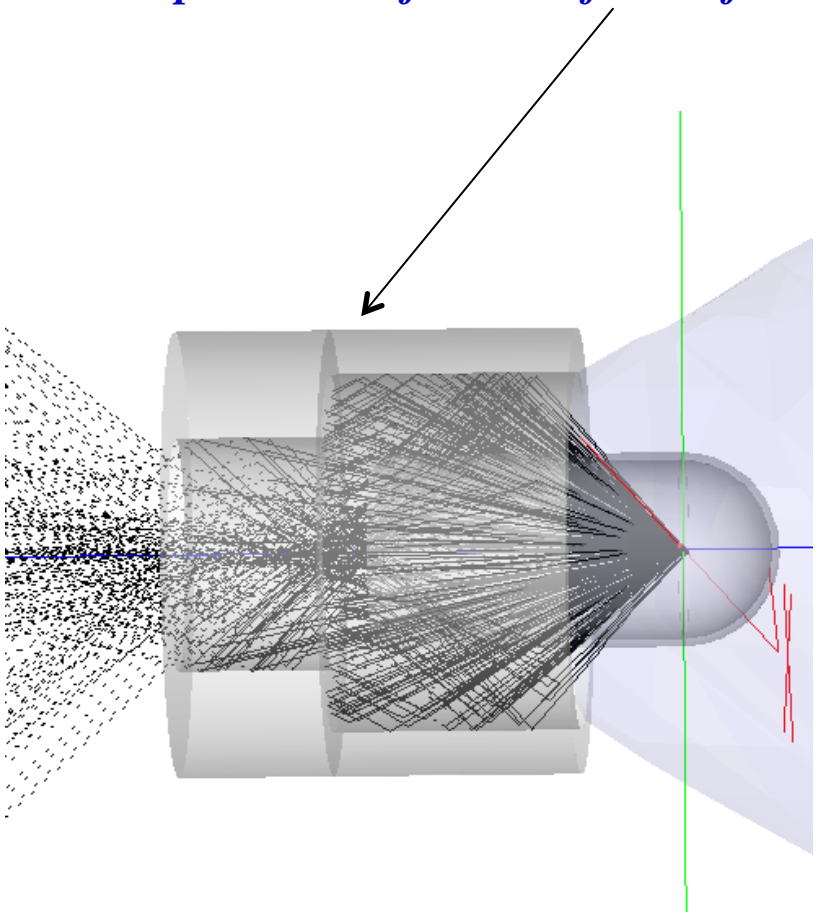
- **Translucent DC93-500 in SWICS lamp assembly is a critical part of the optical path**



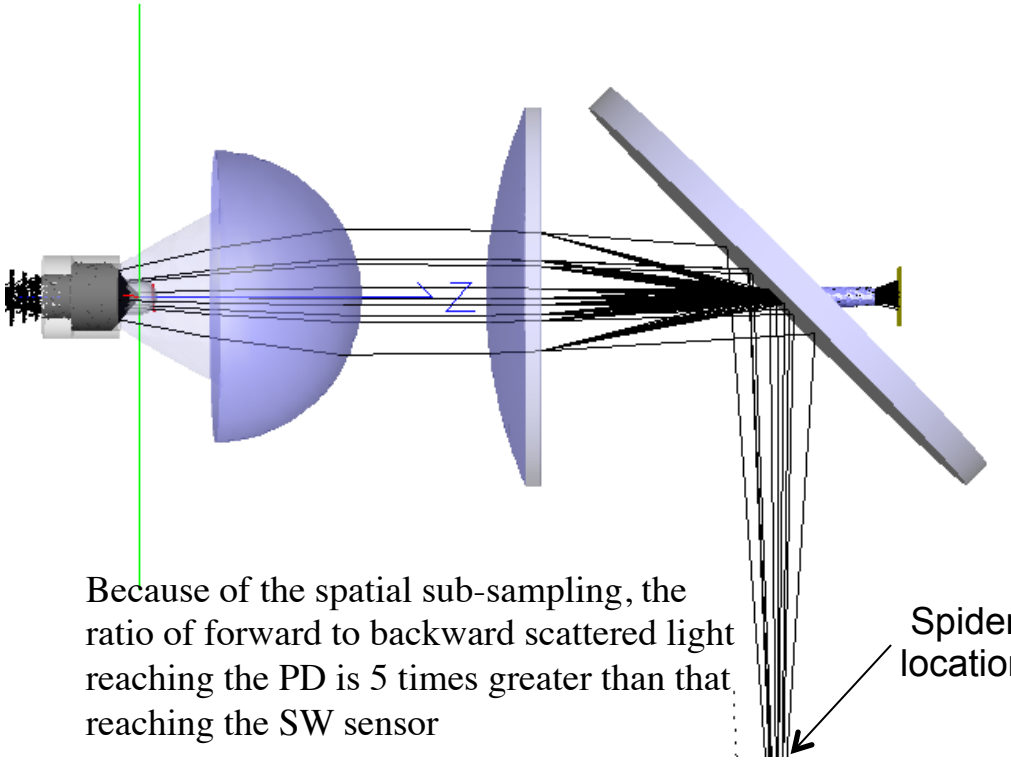


SWICS Ray Trace Model Con't

Rays emitted from the back of the filament scatter forward into the SWICS optical train from the flat surface behind the bulb housing



Because of the location of the flat surface with respect to the lenses, more light scattered from the flat surface reaches the SWICS PD than the SW sensor



Because of the spatial sub-sampling, the ratio of forward to backward scattered light reaching the PD is 5 times greater than that reaching the SW sensor

Spider location

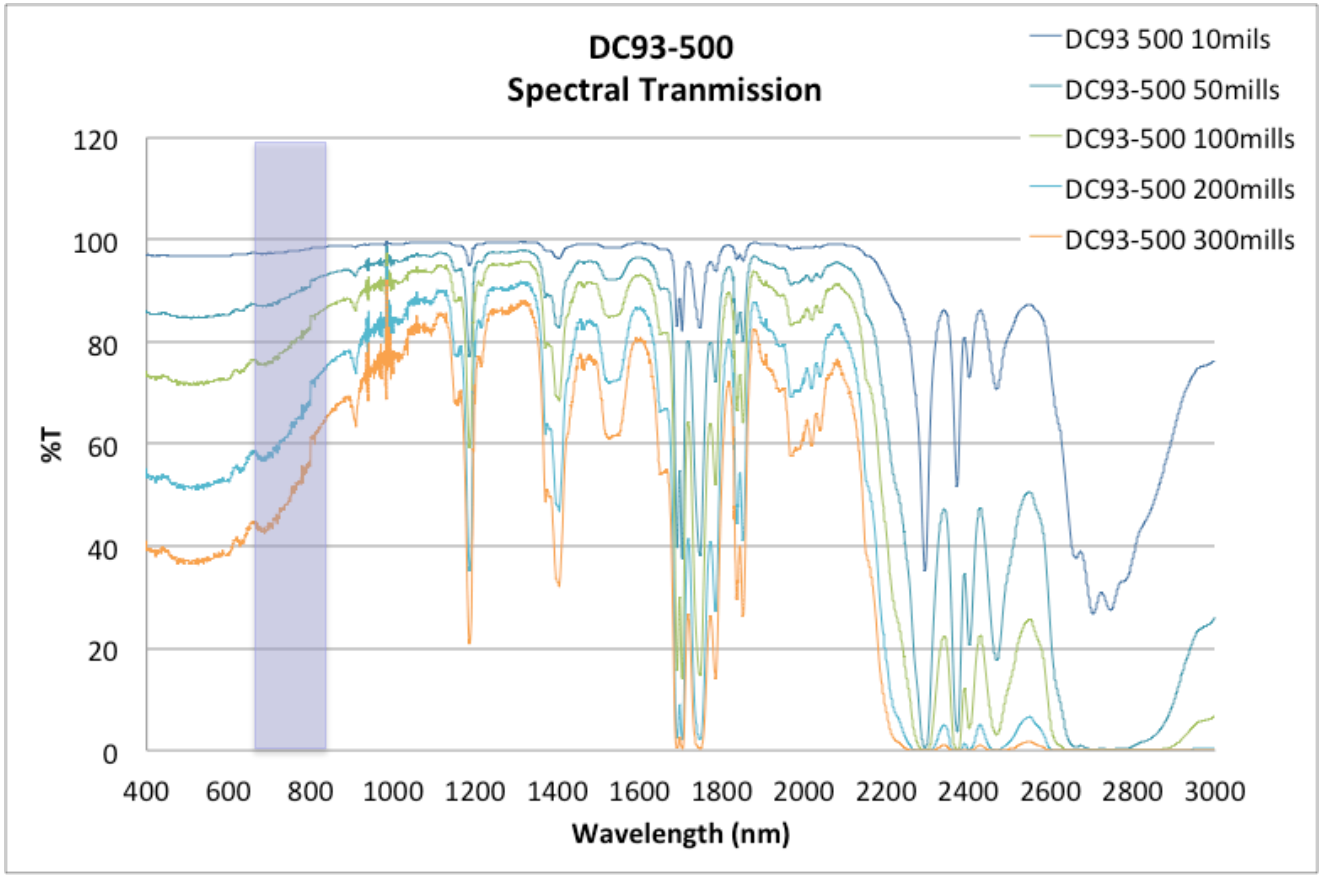
DC93-500 Spectral Transmission

Because of the spectral transmission differences, the amount of light scattered through the RTV and into the FOV of each detector is different and highly dependent on the path length through the RTV

Narrowband PD measures 700nm to 800nm
Broadband SW sensor measures 300nm to > 3µm

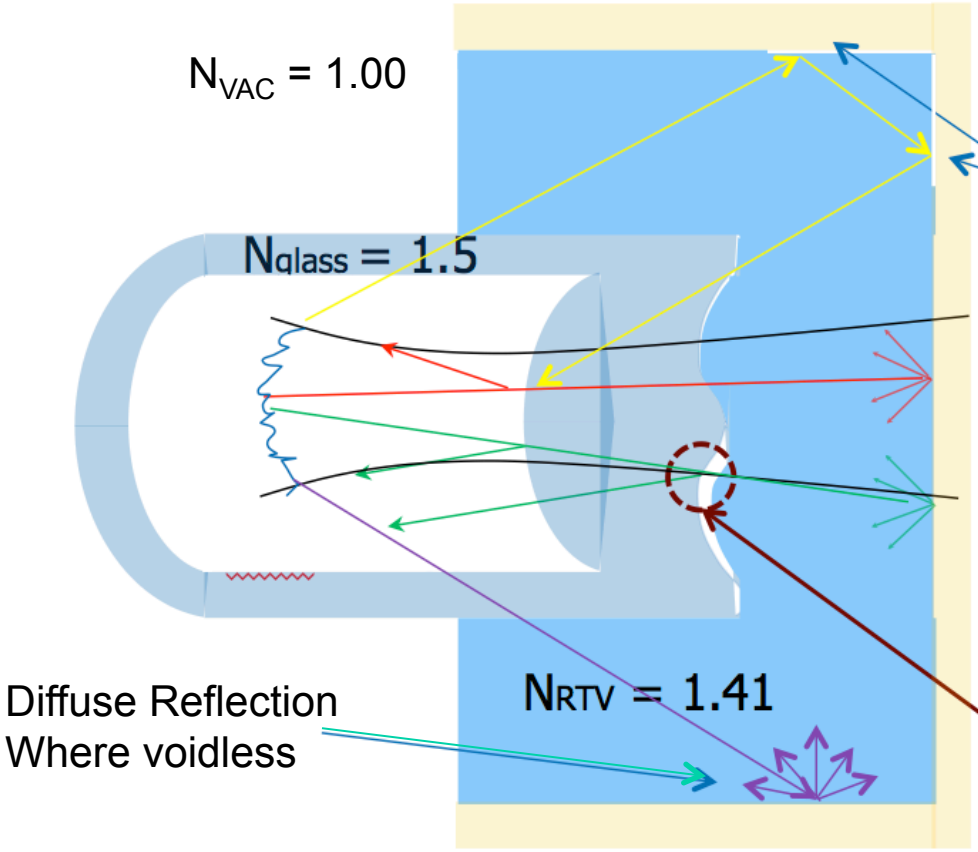
Material transmission changes due to outgassing under vacuum could have a larger impact on the PD because of the spectrally narrow sub sampling

Combined with the larger fractional content of light propagating through the RTV that contributes to the overall signal at the PD, evidence points to this as root cause for the ICM instability



Issues Contributing to Root Cause

Reflectance change due to voids at bond glass/RTV and RTV/Al interface



Debond may cause Total Internal Reflection(**TIR**)
--Reflection = 100%

Diffuse Reflection
Where voidless

2nd surface reflection causes
4% increase in light output

Note: Temp increase tends to shrink voids due to thermal expansion

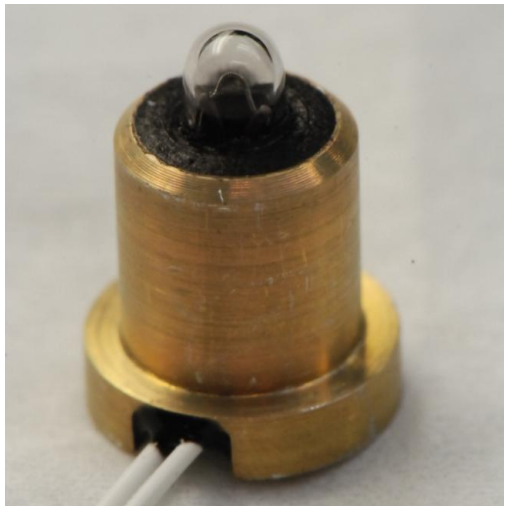
Voids diffuse at Hi Vac , specular reflectance drops, diffuse reflectance increases, Total Light from bulb drops

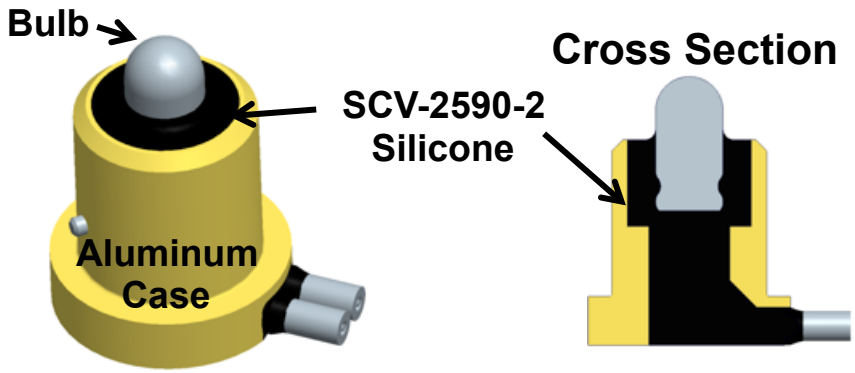
Mounting of the lamp in Assembly identified as Root Problem

- **Translucent DC93-500 in SWICS lamp assembly is a critical part of the optical path**
- **Solution to the problem is to "blacken" the material around the bulb**

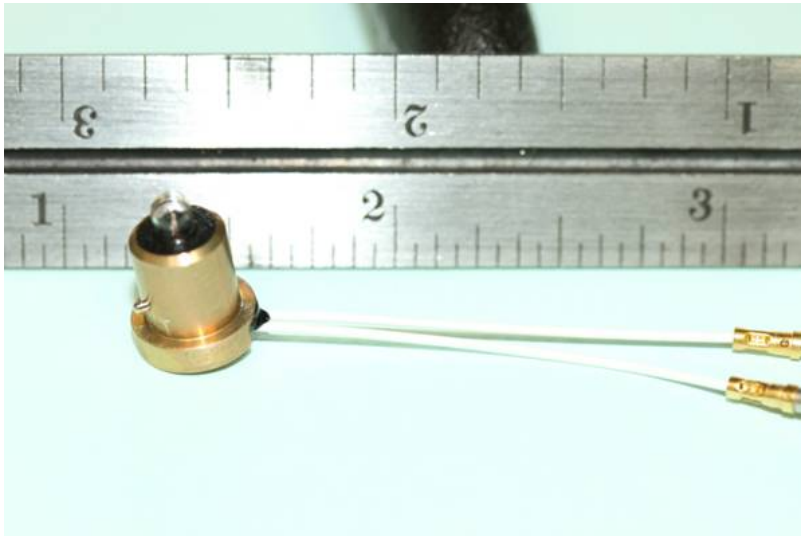
from clear silicone

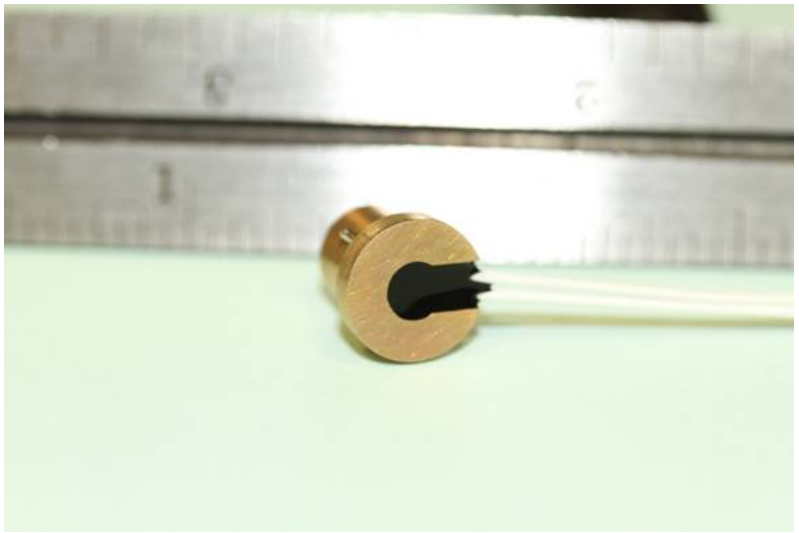
to black silicone

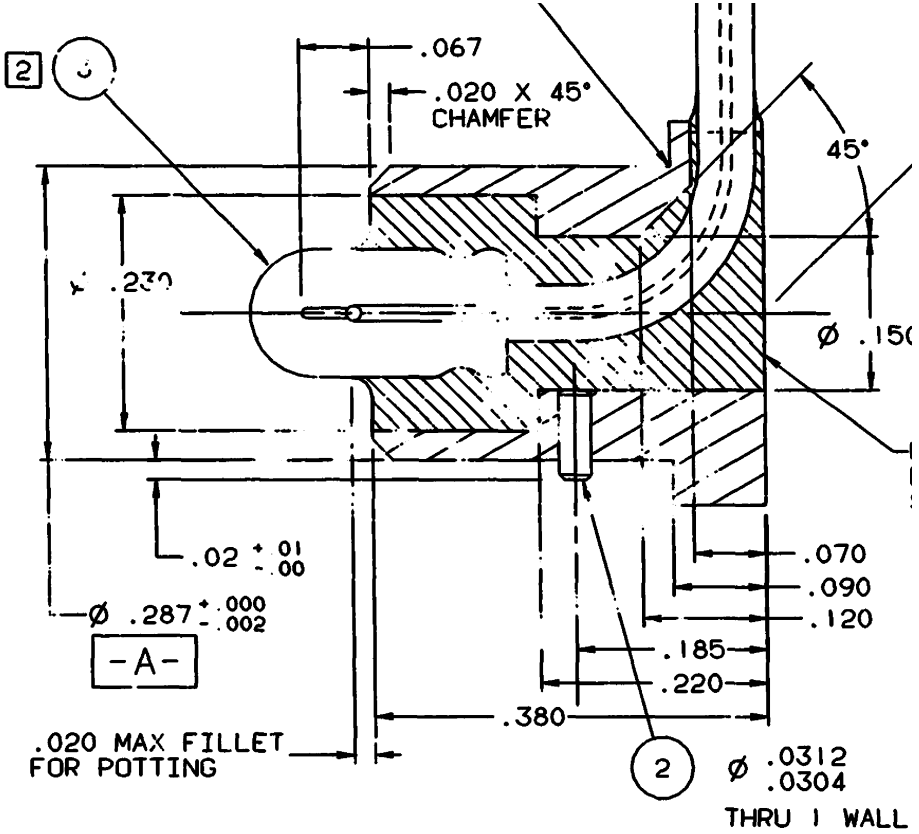




SWICS Lamp Assembly: Black RTV Option







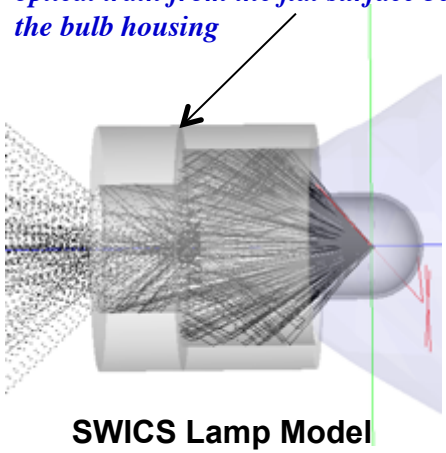
Heritage mount with black RTV

- **Use existing housing**
- **Straightforward material change**
- **Material options: NuSil SCV-2590-2 & CV-2289-2**

Root Cause Summary for ICM SWICS Instability

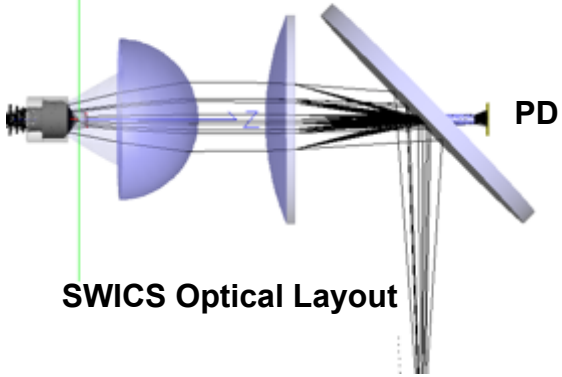
Clouds and the Earth's Radiant Energy System

Rays emitted from the back of the filament scatter forward into the SWICS optical train from the flat surface behind the bulb housing



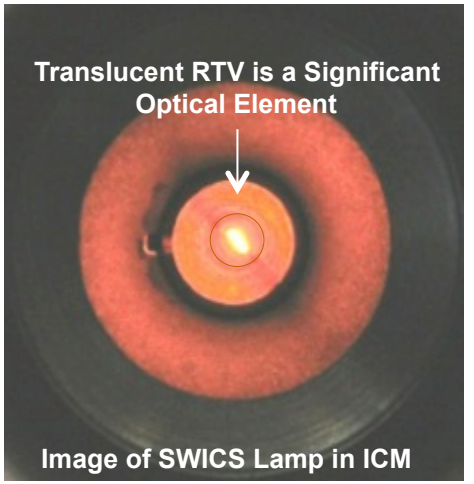
SWICS Lamp Model

Because of the location of the flat surface with respect to the lenses, more of this light reaches the SWICS PD than the SW Sensor (focused light is obscured by the secondary mirror of the SW telescope).

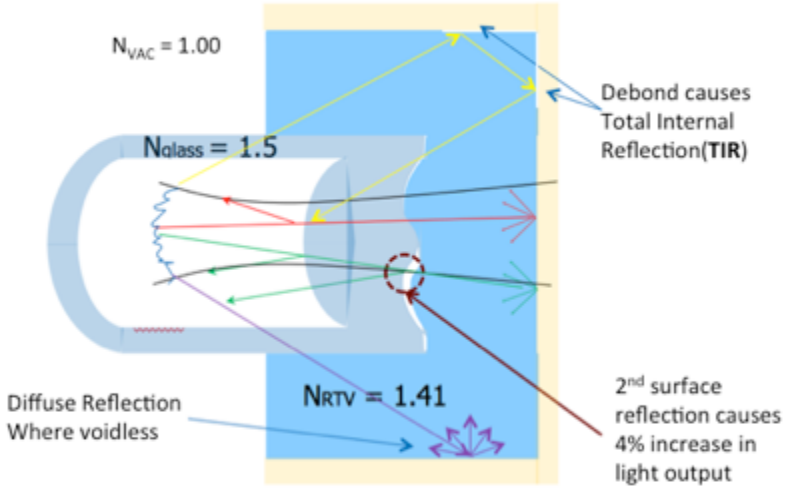


SWICS Optical Layout

SW Sensor



Reflectance changes due to void transformation and changes in bonding at glass/RTV and RTV/Al interface



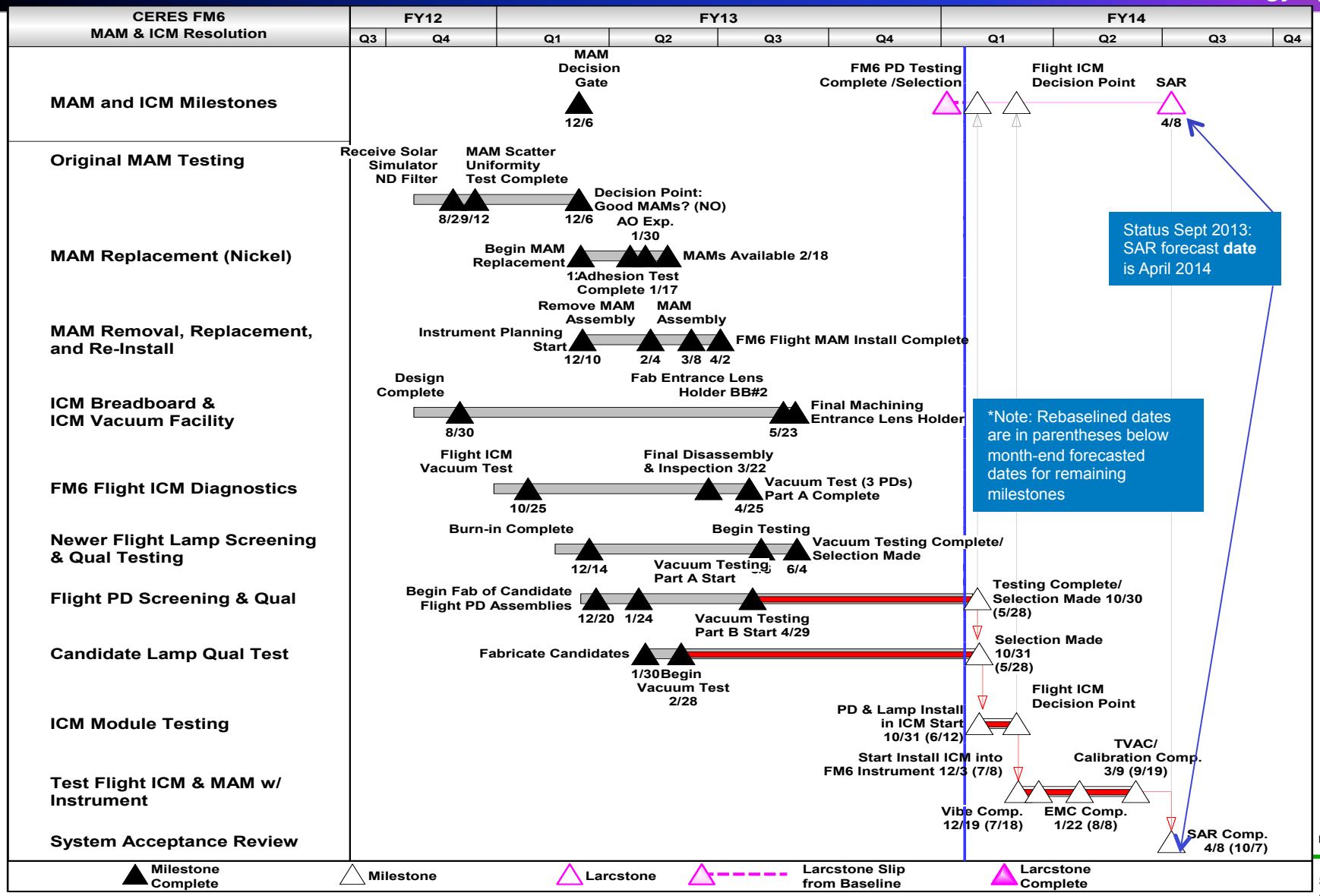
Note: Temp increase tends to shrink voids due to thermal expansion

Voids diffuse at high Vac , specular reflectance drops, diffuse reflectance increases, total light from lamp assembly drops

- **Translucent DC93-500 is a significant optical element in the lamp assembly that changes with temperature**
- **Reflections off the back plane of the lamp housing constitute nearly half of the PD signal, but are mostly obscured by the telescope on the SW Sensor**
- **Changes in the RTV material/optical properties under vacuum cause a slow degradation of the total reflectance of light in the lamp housing**
- **Blackening the medium surrounding the bulb solves the SWICS instability**

CERES FM6 Top Level Schedule & Critical Path

Clouds and the Earth's Radiant Energy System



Milestone Tracking/Forecast

(all dates shown are completion dates)

Clouds and the Earth's Radiant Energy System

ICM (In-Flight Calibration Module)

Task Completion Dates	ETC#3 & delta-EMC revised baseline (May 2013)	Current NGAS Forecast
PD assembly okay for flight	28 May	Complete (22 Oct)
Lamp assembly okay for flight	28 May	Complete (22 Oct)
Lamp/PD Final Install & Re-assemble ICM	12 Jun	7 Nov
ICM Limited TV test	27 Jun	20 Nov
ICM FM6 Install & Checkout	8 Jul	29 Nov

Note: NGAS schedule is based on a 9/80 work week for all activities other than vacuum testing

Instrument Test Campaign

Task Completion Dates	May 2013 revised baseline	Current NGAS Forecast
CFT (Comprehensive Functional Test)	11 Jul	2 Dec
Delta PER (Pre-Environmental Review)	12 Jul	4 Dec
Vibration Test	18 Jul	11 Dec
Post Vibe Alignment Check	25 Jul	17 Dec
EMC	8 Aug	13 Jan
TVAC/ICM Performance	19 Sept	26 Feb
SAR/PSRR	7 Oct	31 Mar

Following completion of the instrument level TVAC/ICM Performance test in the NGAS RCF chamber, instrument removal and a post- TVAC/ICM Performance CFT, 15 work days are planned for preparation for the SAR event .